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M31N 2007-11d: A SLOWLY RISING, LUMINOUS NOVA IN M31

A. W. Shafter[1], A. Rau[2], R. M. Quimby[2], M. M. Kasliwal[2,5], M. F. Bode[3], M. J. Darnley[3], and K. A. Misselt[4]
[1] Department of Astronomy, San Diego State University, San Diego, CA 92182, USA
[2] Division of Physics, Mathematics, and Astronomy, 105-24, California Institute of Technology, Pasadena, CA 91125, USA
[3] Astrophysics Research Institute, Liverpool John Moores University, Birkenhead CH41 1LD, UK
[4] Steward Observatory, University of Arizona, Tucson, AZ 85721, USA
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ABSTRACT

We report a series of extensive photometric and spectroscopic observations of the luminous M31 nova M31N 2007-11d. Our photometric observations coupled with previous measurements show that the nova took at least 4 days to reach peak brightness at $R \simeq 14.9$ on 2007 November 20 UT. After reaching maximum, the time for the nova to decline 2 and 3 mag from maximum light (t_2 and t_3) was ∼9.5 and ∼13 days, respectively, establishing that M31N 2007-11d was a moderately fast declining nova. During the nova's evolution, a total of three spectra were obtained. The first spectrum was obtained one day after maximum light (5 days post-discovery), followed by two additional spectra taken on the decline at two and three weeks post-maximum. The initial spectrum reveals narrow Balmer and Fe II emission with P Cygni profiles superimposed on a blue continuum. These data, along with the spectra obtained on the subsequent decline, clearly establish that M31N 2007-11d belongs to the Fe II spectroscopic class. The properties of M31N 2007-11d are discussed within the context of other luminous novae in M31, the Galaxy, and the LMC. Overall, M31N 2007-11d appears to be remarkably similar to Nova LMC 1991, which was another bright, slowly rising, Fe II nova. A comparison of the available data for luminous extragalactic novae suggests that the $\gtrsim$4 day rise to maximum light seen in M31N 2007-11d may not be unusual, and that the rise times of luminous Galactic novae, usually assumed to be $\lesssim$2 days, may have been underestimated.

Key words: galaxies: individual (M31) – galaxies: stellar content – novae, cataclysmic variables

Online-only material: color figure

1. INTRODUCTION

Classical novae are a subclass of cataclysmic variable systems where a Roche-lobe-filling star (typically a cool, near-main-sequence star) transfers mass to a white dwarf companion (Warner 1995, 2008). Eventually, a thermonuclear runaway (TNR) in the accreted material ensues, which drives substantial mass loss from the system, and leads to the nova eruption (e.g., Starrfield et al. 2008). Absolute magnitudes as bright as $M_V \simeq -10$ have been observed at the peak of eruption. Their high luminosities and high rates of occurrence (∼30 yr^{-1} in a galaxy like the Milky Way; Shafter 2002), make novae powerful probes of the evolution of binary systems in different (extragalactic) stellar populations. The most thoroughly studied extragalactic system is M31, where more than 700 novae have been discovered since Hubble (1929) began his pioneering work in the early 20th century (e.g., see Darnley et al. 2006; Pietsch et al. 2007; Shafter 2008, and references therein).

In November 2007, Nankano (2007) reported the discovery of a slowly rising, and particularly luminous, nova in M31. The nova, M31 2007-11d, was initially detected at $m = 17.7$ (unfiltered) on 2007 November 16.51 before reaching $m = 14.9$ on November 20.385. It was discovered independently by Quimby et al. (2007) as part of the ROTSE IIIb patrol, and a finding chart based on these data showing the position of M31 2007-11d within M31 is shown in Figure 1. According to the compilation of M31 novae by Pietsch et al. (2007), only six (including M31 2007-11d) of the more than 700 novae recorded in M31 have been observed with $m < 15$. Shortly after it became clear that M31 2007-11d was an unusually luminous nova, we initiated a series of photometric and spectroscopic observations to follow its subsequent evolution. Here, we report the results of this campaign.

2. OBSERVATIONS

2.1. Photometry

We extensively monitored M31 2007-11d with the Palomar 60 inch telescope (P60; Cenko et al. 2006), the Faulkes Telescope North (FTN; Burgdorf et al. 2007), and the 2 m Liverpool Telescope (LT; Steele et al. 2004). The P60 observations (see Table 1) started on 2007 November 20.4 UT, 4 days post-discovery, and continued for 21 days until the source faded beyond detectability. Data were reduced within the IRAF[6] environment. Imaging was obtained in the g, r, i', and z' passbands and photometrically calibrated with respect to Sloan Digital Sky Survey (SDSS). The FTN and LT data (see Table 2) were taken through B, V, and Sloan i' filters using the HawkCam and RATCam instruments on the FTN and LT, respectively. These data were reduced using standard routines within IRAF and Starlink, and calibrated against standard stars from Landolt (1992).

In addition to our targeted observations, we have been able to supplement our photometric coverage of M31 2007-11d by extracting unfiltered magnitudes from the ongoing monitoring of M31 taken as part of the ROTSE-IIIb program (see Table 3), and with photometric measurements made on the night of 2007 November 25 using the Mount Laguna Observatory (MLO) 1 m reflector. For the latter observations, the field of the nova was

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[6] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

Table 1
Summary of Palomar 60 inch Photometric Observations

MJD[a] − 54400	g	r	i'	z'
24.416 ± 0.026	15.29 ± 0.02	15.20 ± 0.02	15.22 ± 0.02	15.34 ± 0.03
25.082 ± 0.008	15.46 ± 0.02	15.23 ± 0.02	15.23 ± 0.02	15.31 ± 0.03
25.164 ± 0.003	...	15.25 ± 0.02	15.26 ± 0.02	15.35 ± 0.03
25.237 ± 0.003	15.55 ± 0.02	15.25 ± 0.02	15.23 ± 0.02	15.32 ± 0.03
26.094	...	...	...	15.50 ± 0.03
26.178	...	...	...	15.46 ± 0.03
26.352 ± 0.001	16.03 ± 0.07	15.66 ± 0.06	15.56 ± 0.02	15.49 ± 0.03
27.439 ± 0.002	...	15.91 ± 0.03	16.05 ± 0.03	...
33.100 ± 0.003	16.75 ± 0.03	16.45 ± 0.04	16.69 ± 0.04	16.08 ± 0.04
34.111 ± 0.003	16.92 ± 0.03	16.51 ± 0.05	16.78 ± 0.04	16.26 ± 0.04
37.073 ± 0.003	18.03 ± 0.08	17.12 ± 0.06	...	16.77 ± 0.04
39.071 ± 0.003	20.30 ± 0.10	19.13 ± 0.08	19.12 ± 0.07	18.27 ± 0.06
40.211 ± 0.003	21.24 ± 0.12	20.10 ± 0.10	20.28 ± 0.10	19.05 ± 0.07
45.090 ± 0.004	> 21.5	> 21.5	> 21.3	20.96 ± 0.12
46.096	...	...	...	> 21.2

Notes. [a] MJD ≡ HJD − 2,400,000.5. The date given is the mean time for measurements in the different filters, with the uncertainty representing the range in times.

Table 2
Summary of FTN and LT Photometric Observations

MJD − 54400	Telescope	V	B	i'
27.38	FTN	16.46 ± 0.03	16.07 ± 0.02	15.78 ± 0.01
28.28	FTN	16.52 ± 0.04	16.24 ± 0.03	15.89 ± 0.03
29.28	FTN	16.56 ± 0.03	16.33 ± 0.02	16.04 ± 0.01
31.97	LT	16.64 ± 0.03	16.60 ± 0.02	16.31 ± 0.01
36.09	LT	17.56 ± 0.03	17.56 ± 0.03	17.07 ± 0.01
36.28	FTN	17.82 ± 0.07	17.70 ± 0.04	17.27 ± 0.03
38.87	LT	20.22 ± 0.04	20.04 ± 0.04	18.71 ± 0.02
42.84	LT	21.77 ± 0.03	21.44 ± 0.13	20.27 ± 0.07
48.84	LT	...	...	20.88 ± 0.09

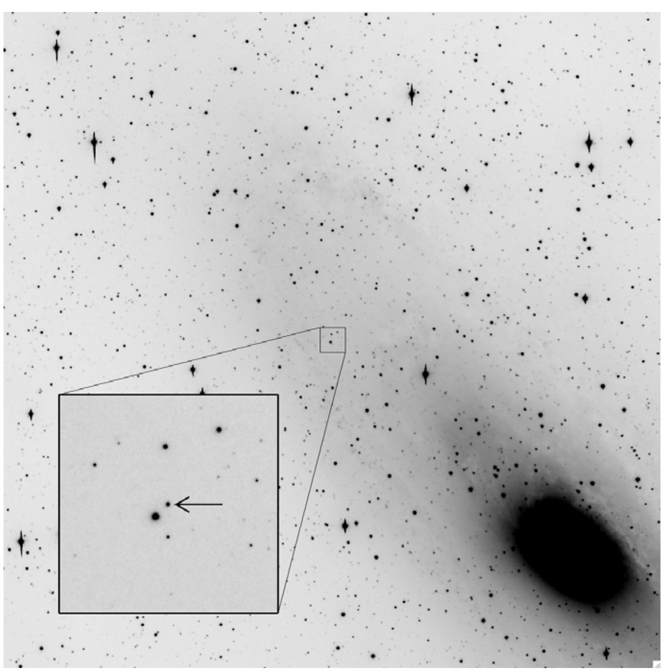

Figure 1. Messier 31 as observed by ROTSE-IIIb and P60 showing the location of M31N 2007-11d. The large image is a co-addition of archival ROTSE-IIIb images, with the inset ($\sim 2.5' \times 2.5'$ on a side) based on a P60 image from 2007 November 21. North is up and East is to the left.

Table 3
ROTSE IIIb Photometry

MJD − 54400	Unfiltered Mag	Limiting Mag
15.08	...	18.79
16.06	...	18.66
17.13	...	19.17
18.06	...	19.09
20.06	17.80 ± 0.25	17.78
21.06	17.24 ± 0.11	18.91
23.08	15.76 ± 0.03	18.95
24.06	15.30 ± 0.02	18.45
25.06	15.42 ± 0.03	17.96
27.08	16.03 ± 0.05	18.00
28.06	16.18 ± 0.06	18.03
31.07	16.75 ± 0.22	16.53
32.07	16.46 ± 0.06	18.86
33.10	...	11.87
34.06	17.06 ± 0.12	17.68
36.06	17.39 ± 0.19	17.39
37.06	17.52 ± 0.15	19.16
38.06	17.70 ± 0.43	18.13
39.06	18.47 ± 0.53	18.89
40.06	...	19.05
42.07	...	19.02
43.06	...	18.67

imaged with a Loral CCD detector through B, V, and R filters. As with the FTN and LT data, the MLO observations were reduced with standard routines in IRAF, and calibrated with standard stars from Landolt (1992). M31N 2007-11d had faded to $V = 16.31$ by the time of the MLO observations, and was characterized at that time by $B - V = 0.22$ and $V - R = 0.27$.

Our comprehensive light curve for M31 2007-11d is shown in Figure 2. In addition to the extensive photometry on the decline from maximum, we have also included some early unfiltered CCD measurements by K. Nishiyama and F. Kabashima as communicated by Nakano,[7] which are useful in establishing the time of maximum light, and in constraining the rise time of the eruption. The time interval between the initial discovery on 2007 November 16.51 and the time the nova reached peak

[7] http://www.cfa.harvard.edu/iau/CBAT_M31.html.

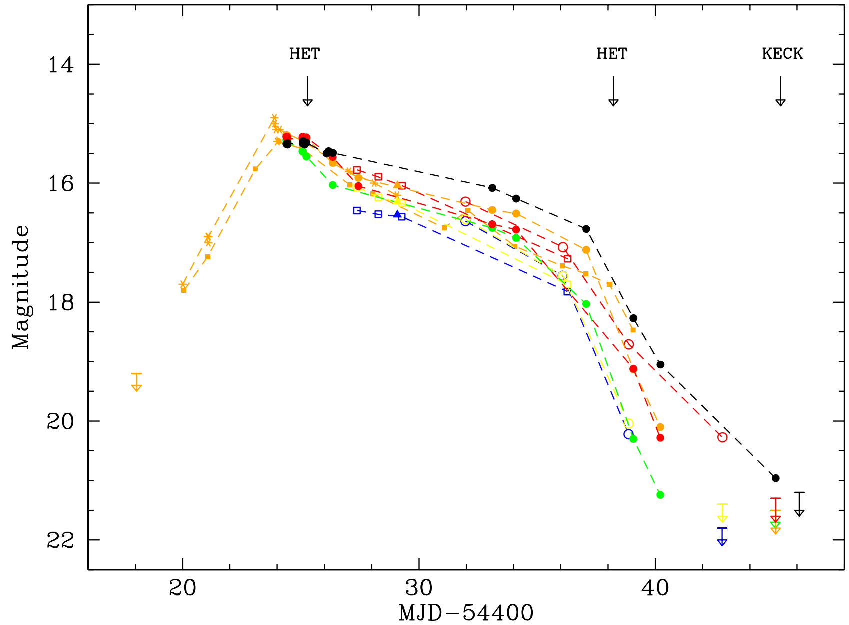

Figure 2. Light curve of M31N2007-11d. Key: P60 – filled circles (g, green; r, orange; i', red; and z', black), FTN – open squares (B, blue; V, yellow; i', red), LT – open circles (B, blue; V, yellow; i', red), MLO – filled triangles (B, blue; V, yellow; R, orange). Also shown are pre-maximum measurements from K. Nishiyama and F. Kabashima (orange asterisks) and ROTSE-IIIb (orange filled squares). The times of our spectroscopic observations are indicated by the arrows. Note the relatively slow rise to maximum, and the rapid diminution in brightness near the time of our second HET spectrum.

(A color version of this figure is available in the online journal.)

brightness on November 20.4 allows us to set a lower limit of ∼4 days on the rise to maximum. On the subsequent decline, the light curve indicates that M31 2007-11d was a relatively "fast" nova, with times to decline by 2 and 3 mag (V-band) from maximum light ($t_2[V]$ and $t_3[V]$) of 9.5 and 13 days, respectively. The corresponding decline rate of $\sim 0.22 \pm 0.01$ mag d^{-1} is consistent with those of other luminous novae in M31 (Capaccioli et al. 1989).

2.2. *Spectroscopy*

Our spectroscopic observations of M31 2007-11d were obtained with both the Hobby–Eberly Telescope (HET) and the Keck-I Telescope. The HET observations were made with the Low Resolution Spectrograph (LRS; Hill et al. 1998) as part of an ongoing spectroscopic survey of novae in M31. We used the $g1$ grating with a 1.″0 slit and the GG385 blocking filter, which covers 4150–11000 Å with a resolution of $R \sim 300$, although we limit our analysis to the 4150–8900 Å range where the effects of order overlap are minimal. The Keck-I data were taken in long-slit mode with the Low Resolution Imaging Spectrograph (LRIS; Oke 1995). LRIS is a dual-beam instrument in which the light is split by a dichroic, and spectra can be obtained in two channels simultaneously. We obtained 600 s exposures with the 400/3400 (dispersion of 1.″09 pixel^{-1}) grating and the 400/8500 (1.″86 per pixel) grism on the blue and red sides, respectively. Both the HET and Keck spectra were reduced using standard IRAF routines, and are shown in Figures 3 and 4, respectively. For reference with the light curve, the dates when these spectra were obtained are indicated in Figure 2.

Our initial HET spectrum was taken on 2007 November 21 UT, roughly 5 days after the nova began to brighten (∼ 1 day post-maximum) when M31N 2007-11d was at $V \sim 15.5$. The spectrum is dominated by Balmer, Fe II, and P Cygni emission features (FWHM $\simeq$ 1600 km^{-1}) superimposed on a very blue continuum. These features are characteristic of a nova caught at maximum light, but are unusual for a nova 5 days post-discovery. This discrepancy can be attributed to the relatively slow rise to maximum exhibited by M31N 2007-11d. Overall, the spectrum is consistent with a classification as an Fe II nova in the system of Williams (1992).

A follow-up HET spectrum, also shown in Figure 3, was obtained on 2007 December 4, 18 days post-eruption (∼14 days after maximum). Our photometry indicates that the nova had declined to $V \sim 19$, more than 4 mag from maximum light, and was fading rapidly. As is typical of the early spectral development of novae, the spectrum changed dramatically from that near maximum light, with the fading of the strong blue continuum and the disappearance of the P Cygni profiles. The spectrum became dominated by strong Balmer (FWHM ∼ 2300 km s^{-1}), Fe II and O I lines in emission, confirming the identification of M31N 2007-11d as an Fe II-type nova.

Our final spectrum (Figure 4) was obtained on 2007 December 11.5 UT after M31N 2007-11d had faded to well below $V = 21$. By this time, most emission features had faded significantly, with only residual Hα emission (FWHM ∼ 1800 km s^{-1}) being clearly detected.

3. DISCUSSION

3.1. *The Observed M31 Nova Luminosity Distribution*

By the end of 2007, a total of 779 novae have been discovered in M31 since Hubble's observations began nearly a century ago (Hubble 1929). Of these, 732 novae have measured magnitudes (Pietsch et al. 2007). The interpretation of these data is complicated because all novae were not observed on the same photometric system or in the same bandpass. Most of the early observations yielded photographic magnitudes, while much of the later data yielded either unfiltered or Hα magnitudes. Typically, observations have been reported in one or more of the m_{pg}, U, B, V, R, I, W (unfiltered), and Hα bandpasses.

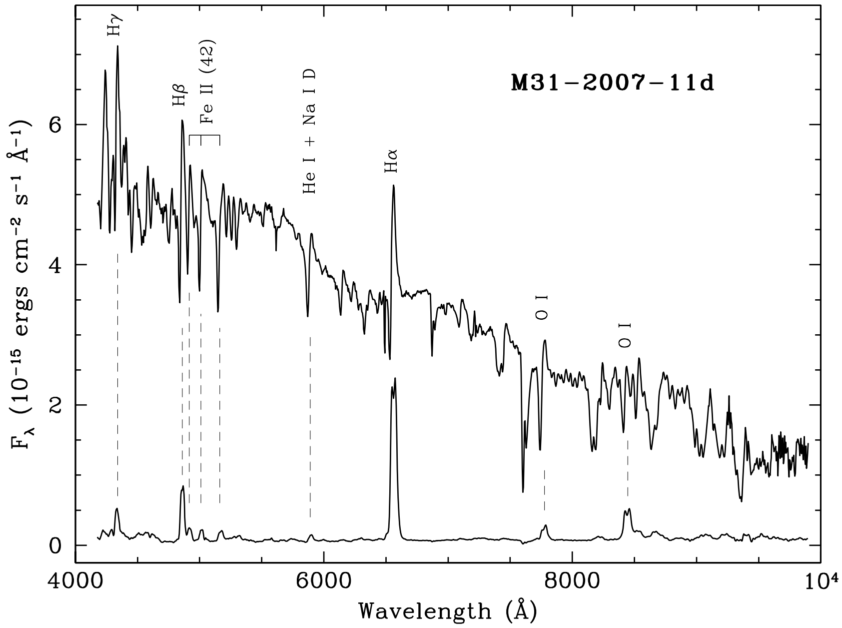

Figure 3. Low-resolution spectra of M31N2007-11d taken with the LRS on the HET $\sim$ 5 days after discovery and near maximum light (upper spectrum), and $\sim$18 days after discovery (lower spectrum). The initial spectrum is characterized by Balmer and Fe II emission with P Cygni profiles. As the nova faded, the spectrum evolved into a standard Fe II type.

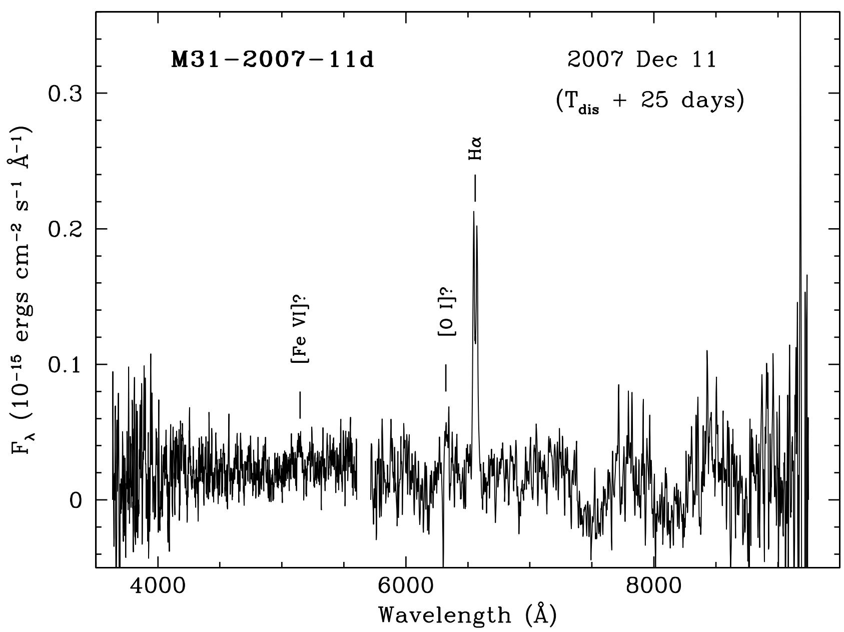

Figure 4. Low-resolution spectrum taken with the Keck/LRIS $\sim$ 25 days post-discovery when the nova had faded significantly.

In order to compare the data better, we have attempted to convert all individual photometric observations to a reddening-free visual magnitude, V_0. We began this process by correcting all observations for foreground extinction using a reddening of $E(B-V) = 0.062$ along the line of sight to M31 found by Schlegel et al. (1998).[8] From this, we estimate $A_U = 0.30$, $A_B = A_{pg} = 0.25$, $A_V = 0.20$, $A_R = A_{H\alpha} = A_W = 0.15$, and $A_I = 0.10$, where the Hα and W (unfiltered) CCD magnitudes have been treated as R-band measurements since the effective wavelengths are similar. After correcting for extinction, we converted all observations to the visual band by adopting representative colors for a typical nova shortly after eruption. Van den Bergh & Younger (1987) have shown that the mean colors of Galactic novae are given by $\langle B-V\rangle_0 = 0.23 \pm 0.06$ at maximum light, and $\langle B-V\rangle_0 = -0.02 \pm 0.04$ by the time the average nova had faded 2 mag below maximum. Since we expect that the typical M31 nova will have faded somewhat by the time of discovery, here we adopt $\langle B-V\rangle_0 \simeq 0.15$ as a plausible estimate for the color at the time of the photometric measurements. This value is consistent with the de-reddened color of M31N 2007-11d, $(B-V)_0 = 0.16$, based on our MLO observations obtained $\sim$5 days post maximum. According to the data compiled by Johnson (1966), this is the approximate color of an A5V star, which is also characterized by $(U-B)_0 = 0.11$,

[8] We have made no attempt to correct for extinction internal to M31, which is highly variable and difficult to quantify based on the data available for individual novae.

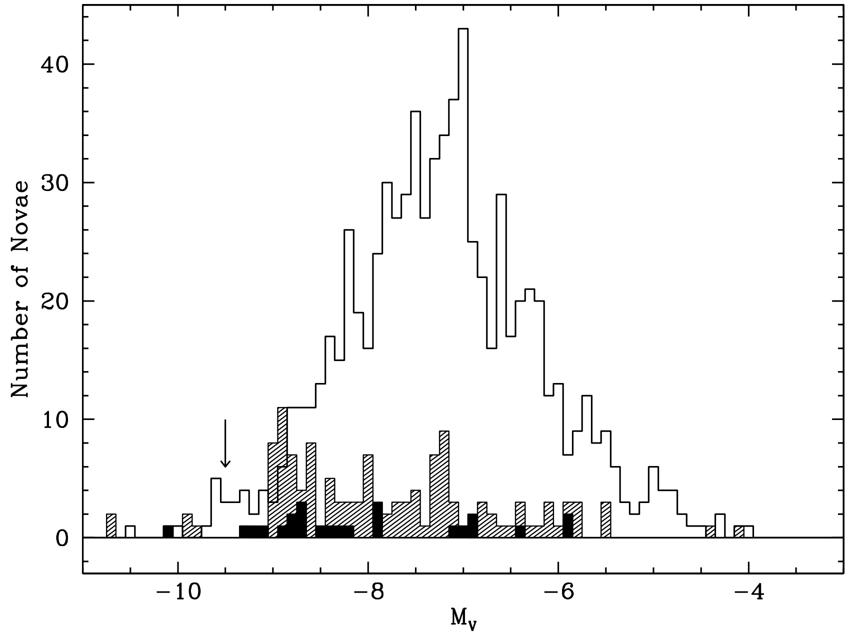

Figure 5. Absolute visual magnitude distribution of the 732 M31 novae after making corrections for foreground extinction, bandpass of observation, and distance to M31. For comparison, the cross-hatched and filled regions show the M_V distributions for 127 Galactic novae and 24 LMC novae, respectively. The arrow shows the position of M31N 2007-11d.

$(V - R)_0 = 0.16$, and $(R - I)_0 = 0.06$. Since the energy distribution of a nova near maximum light is similar to a blackbody, we can use these color indicies to convert all M31 nova observations to a de-reddened V magnitude (photographic magnitudes were initially converted to B_0 magnitudes using the relationship, $[B - m_{pg}]_0 = 0.27 - 0.19[B - V]_0$ from Arp 1961).

Given the distance of M31 ($\mu_0 = 24.38$; Freedman et al. 2001), values of V_0 result in the absolute magnitude distribution shown in Figure 5, with the position of M31 2007-11d ($M_V \simeq -9.5$) indicated by the arrow. It is important to note that since all the photometric measurements of M31 novae were not obtained precisely at maximum light, this distribution is only an approximation to the true maximum-magnitude distribution of novae in M31. Nevertheless, it is likely that the majority of systems were observed near maximum, particularly for novae at the brighter end of the distribution. Clearly, M31 2007-11d, which we estimate reached an absolute magnitude at maximum light of $M_V \simeq -9.5$, is one of the brightest novae to erupt in M31 over the past century.

3.2. *Evidence for Two Nova Populations?*

There has been a growing body of evidence from both Galactic and extragalactic observations that there may exist two separate populations of novae (e.g., see Shafter 2008, and references therein). This conjecture is based primarily on three principal findings: (1) the frequency distribution of nova magnitudes at maximum light from the Arp (1956) M31 nova survey is bimodal, possibly as a result of two distinct populations of progenitor systems (there is also some evidence for bimodality in the Rosino 1973 M31 survey, but it is less compelling); (2) Galactic observations suggesting that novae associated with the disk may be on average faster and more luminous than novae thought to be associated with the bulge (e.g., Duerbeck 1990; Della Valle et al. 1992); (3) the distribution of the rates of decline for novae in the LMC suggesting that these novae are on average "faster" than those in the bulge of M31 (Della Valle & Duerbeck 1993); and (4) the realization that novae can be divided into two principal classes based upon their spectroscopic properties (Williams 1992). Novae with prominent Fe II lines (the Fe II novae) usually show P Cygni absorption profiles, and tend to evolve more slowly, have lower expansion velocities, and have a lower level of ionization compared with novae that exhibit strong lines of He and N (the He/N novae). Later, Della Valle & Livio (1998) noted that Galactic novae that were classified as He/N were concentrated near the Galactic plane, and tended to be faster and more luminous compared with their Fe II counterparts.

Assuming that the bimodal magnitude distribution seen by Arp (1956) and later emphasized by Capaccioli et al. (1989) is in fact real, it is perhaps surprising that the absolute magnitude distribution for our much larger sample of M31 novae, shown in Figure 5, shows no evidence for bimodality. This discrepancy may be attributed to the fact that many of the M31 novae in our sample likely had faded somewhat by the time of discovery, in which case, as noted earlier, the absolute magnitudes used to construct Figure 5 do not correspond to maximum light. Nevertheless, given the likelihood that the majority of novae were observed near peak brightness, it would seem reasonable to expect some trace of bimodality to remain in the distribution.

Another approach to test the existence of two distinct nova populations is to compare the absolute magnitude distribution of the M31 novae with similar distributions for the Galaxy and the LMC. Novae in M31 are thought to arise mainly from the galaxy's bulge population (Ciardullo et al. 1987; Capaccioli et al. 1989; Shafter & Irby 2001; Darnley et al. 2006), while those in the Galaxy and in the LMC are associated primarily with a younger stellar population. Although Galactic novae occur both in the bulge and disk, the observed nova sample is biased by relatively nearby objects, which are mostly members of the disk population. Similarly, novae in the LMC have been found to belong primarily to a young population, with progenitors estimated to be in the age range of 1–3.2 Gyr (Subramaniam

Table 4
Properties of Luminous Galactic Novae with $M_V \lesssim -9.0$

Nova	Spectral Class	t_R (d)	t_2 (d)	M_V	References
V500 Aql	He/N?	...	17	−9.0	1
V603 Aql	Hy	$\gtrsim 1$	4	−9.0	1–4
V476 Cyg	Fe II	$\gtrsim 4$	6	−9.9	1, 2, 5
V1500 Cyg	Hy	~ 1	2.4	−10.7	1, 2, 6
V446 Her	He/N	...	7	−9.9	1, 2
CP Lac	Hy	$\gtrsim 2$	5.3	−9.3	1, 2, 7
DK Lac	Fe II	$\gtrsim 3$	11	−9.8	1, 2, 8
GK Per	He/N	$\gtrsim 1$	7	−9.0	1, 2, 9
CP Pup	He/N	$\gtrsim 2$	6	−10.7	1, 2, 10
V838 Her	He/N	...	1.2	−9.0	2, 3, 11
V977 Sco	Fe II	...	3.4[a]	−9.0	3, 12
MU Ser	He/N	...	2	−9.0	3, 13

Notes. [a] Estimated from t_3 using the relationship $t_2 \simeq (t_3/2.75)^{1.14}$ from Warner (1995).
References. (1) Downes & Duerbeck 2000; (2) Della Valle & Livio 1998; (3) Shafter 1997; (4) Duerbeck 1987; (5) Denning 1920; (6) Liller et al. 1975; (7) Bertaud 1945; (8) Bertaud 1950; (9) Campbell 1903; (10) Dawson 1942; (11) Leibowitz 1993; (12) Liller 1993; (13) Schlegel et al. 1985.

& Anupama 2002). If novae arising from a younger stellar population are on average more luminous than their bulge counterparts, this difference should be reflected in the luminosity distributions for the three galaxies.

To test this possibility, absolute magnitude distributions for Galactic and LMC novae have been included in Figure 5 for comparison with the M31 distribution. The Galactic data come directly from the compilations of Downes & Duerbeck (2000) and Shafter (1997), while the LMC nova luminosities have been computed from the apparent magnitudes given by Shida & Liller (2004) assuming $\mu_0(\text{LMC}) = 18.5$ and $A_V = 0.4$ (van den Bergh 2000). Although the Galactic and M31 magnitude distributions agree reasonably well at the bright end as expected, the mean absolute magnitudes of the Galactic and LMC samples ($\langle M_V \rangle = -7.79 \pm 0.11$ and $\langle M_V \rangle = -8.06 \pm 0.05$, respectively) are significantly brighter than the mean of the M31 sample ($\langle M_V \rangle = -7.20 \pm 0.04$). As just alluded to with regard to the lack of bimodality in the overall magnitude distribution, it is likely that some of this discrepancy can be attributed to the fact that many M31 novae have faded somewhat from maximum light by the time of discovery. In addition, extinction internal to M31, for which we have made no correction, will also lower our estimates of the M31 nova luminosities. However, it is also possible that part of the discrepancy is real, and that it results from the differences in the underlying nova populations. In this case, since the Hubble type of M31 (Sb) is significantly earlier than that of the LMC (Irr I) and slightly earlier than that of the Galaxy (Sbc), M31 would be expected to contain a greater fraction of bulge novae compared with the latter galaxies.

3.3. Properties of Luminous Novae

In Tables 4–6, we summarize properties of novae in the Galaxy, M31, and the LMC that have reached absolute visual magnitudes brighter than $M_V = -9.0$. In addition to their absolute magnitudes, we have listed, when available, data for the rise time to maximum light, t_R, the time to fade by 2 mag from maximum light, t_2, and the spectroscopic class. Novae exhibit a well-known relationship between their peak luminosity and their rate of decline known as the maximum-magnitude versus rate-of-decline (MMRD) relation (McLaughlin 1945; Della Valle & Livio 1995; Downes & Duerbeck 2000). In his discussion of Nova LMC 1991, Della Valle (1991) pointed out that several novae, in addition to Nova LMC 1991, reached peak luminosities about a magnitude brighter than than expected from the mean MMRD relation. He concluded that a distinct "super-bright" population of novae may exist.

To explore this possibility further, and to see where M31N 2007-11d fits into this picture, in Figure 6 we have plotted the peak luminosities (M_V[max]) and corresponding fade rates (t_2) for our samples of luminous Galactic, M31, and LMC novae. Since our samples are restricted to $M_V < -9.0$, the plot only shows the bright end of the MMRD relation (i.e., less luminous novae lying in the shaded region are not shown). To assess better the fit to the full MMRD relation, the reader is referred to the studies by Della Valle & Livio (1995) and Downes & Duerbeck (2000). Despite its limitations, Figure 6 reveals that there is considerable scatter at the bright end of the luminosity function with little correlation of the maximum magnitude with t_2. Both M31N 2007-11d and Nova LMC 1991 are close to a magnitude brighter than predicted by the nonlinear MMRD relation of Della Valle & Livio (1995) (less so for the linear relation of Downes & Duerbeck 2000 for Galactic novae), but it is not clear that they form part of a separate class of super-bright novae. This view is supported by the luminosity distribution shown in Figure 5, where no evidence for a separate class is seen. Instead, we argue that the scatter seen in Figure 6 results from a combination of observational uncertainties (e.g., in extinction corrections) coupled with the intrinsic variability one expects from a population of novae with a distribution of fundamental properties (e.g., white dwarf masses, mass accretion rates, metallicites).

As mentioned earlier, there is evidence that the LMC novae fade more quickly (i.e., have a lower mean t_2) compared with Galactic and M31 novae. The data for luminous novae from Tables 4–6 appear to be consistent with this picture with $\langle t_2 \rangle = 6.0 \pm 4.4$ days, $\langle t_2 \rangle = 10.6 \pm 3.8$ days, and $\langle t_2 \rangle = 3.7 \pm 1.7$ days for the Galaxy, M31, and the LMC, respectively. Furthermore, referring to Table 6, we know that in the LMC four novae (perhaps five if V2434-LMC is included) have $M_V \lesssim -9.0$. This number is quite high given only ∼34 novae have been discovered in the LMC (Shida & Liller 2004). Thus, luminous novae ($M_V \lesssim -9.0$) account for roughly 12% of

Table 5
Properties of Luminous M31 Novae with $M_V \lesssim -9.0$

Nova	Spectral Class	t_R (d)	t_2 (d)	M_V	References
M31N 1925-09a	...	$\gtrsim 1$	> 8	−9.3	1
M31N 1932-07a	Fe II	$\gtrsim 4$	10	−9.1	2
M31N 1960-11a	...	$\gtrsim 2$	7	−9.7	3
M31N 1963-09b[a]	...	...	...	−9.5	3
M31N 1964-11b	...	$\gtrsim 3$	> 7	−9.6	3
M31N 1965-12a	...	$\gtrsim 4$	< 6	−9.3	3
M31N 1967-10c	...	...	> 11	−9.6	4
M31N 1975-02a	...	$\gtrsim 1$	...	−9.2	4
M31N 1981-09b	...	...	...	−9.3	5
M31N 1981-09c	...	...	...	−9.2	5
M31N 1982-08b	...	$\gtrsim 1$	< 13	−9.2	6
M31N 1983-01a[b]	...	...	< 3.3	−9.5	6–8
M31N 1983-09d[c]	...	> 32	...	−10.5	9
M31N 1983-10a[c]	...	> 3	...	−10.1	9
M31N 1983-10b[c]	...	...	...	−9.4	9
M31N 1984-10b[c]	...	...	...	−9.0	9
M31N 1985-10c[c]	...	> 3	...	−9.2	9
M31N 1990-12c	...	...	> 2	−9.7	6
M31N 1991-01a	...	...	...	−9.7	10
M31N 1993-01a[c]	...	> 3	...	−9.1	11
M31N 1995-12a	...	...	...	−9.4	12
M31N 1996-08g	...	$\gtrsim 3$	> 3	−9.7	13
M31N 1998-07n[d]	...	$\gtrsim 5$	> 4	−10.0	14, 15
M31N 2004-09b	...	...	...	−9.3	16
M31N 2005-01a	...	$\gtrsim 3$	16	−9.4	17
M31N 2007-11d	Fe II	$\gtrsim 4$	9.5	−9.5	18

Notes.
[a] Maximum magnitude is uncertain; based on extrapolation.
[b] Object questionable; not confirmed by Sharov & Alksnis (1992).
[c] Observations in Hα; the rise times likely do not reflect the behavior in the continuum.
[d] Magnitude at maximum light from Modjaz et al. (1998) and Sharov et al. (2000) differ significantly, making M_V particularly uncertain.
References. (1) Hubble 1929; (2) Humason 1932; (3) Rosino 1973; (4) Henze at al. 2008; (5) Ciardullo et al. 1983; (6) Sharov & Alksnis 1992b; (7) Bryan & Brewster 1983; (8) Sharov & Alksnis 1992a; (9) Ciardullo et al. 1987; (10) Birkle et al. 1991; (11) Shafter & Irby 2001; (12) Ansari et al. 2004; (13) Sharov & Alksnis 1997; (14) Modjaz et al. 1998; (15) Sharov et al. 2000; (16) Tzenev et al. 2004; (17) Hornoch et al. 2005; (18) this work.

Table 6
Properties of Luminous LMC Novae with $M_V \lesssim -9.0$

Nova	Spectral Class	t_R (d)	t_2 (d)[a]	M_V	References
LMC 1978a[b]	He/N?	...	3.5	−9.2	1, 2
LMC 1987	...	...	2.0	−9.3	1, 3
LMC 1990a	He/N	...	3.4	−9.2	1, 4
LMC 1991	Fe II	$\gtrsim 10$	6.0	−10.1	1, 5–10
V2434-LMC[c]	...	...	$\lesssim 1$	−9.2	1, 11

Notes.
[a] t_2 values from Della Valle (1991).
[b] Maximum magnitude is uncertain; based on extrapolation.
[c] Nature of object uncertain; possible nova.
References. (1) Shida & Liller 2004; (2) Graham 1979; (3) McNaught & Garradd 1987; (4) Dopita & Rawlings 1990; (5) Della Valle 1991; (6) Gilmore & Liller 1991; (7) Della Valle et al. 1991; (8) Dopita et al. 1991; (9) Williams et al. 1994; (10) Schwarz et al. 2001; (11) Liller & Morel 2002.

the total. In contrast, only a dozen ($\sim 9\%$) out of the 127 Galactic novae with measured luminosities ($\sim 5\%$ of all Galactic novae), and only 26 out of the 732 M31 novae ($\sim 4\%$) have similarly high luminosities.

Finally, although Fe II novae account for the majority ($\sim 80\%$) of all Galactic novae (Shafter 2007b), only three of the 12 Galactic novae with $M_V \leqslant -9$ are members of the Fe II class. The remaining nine systems are either He/N novae or hybrid (Hy) objects thought to be related to the He/N systems. The LMC data, though limited, support the conclusion that the He/N novae are overrepresented among the luminous novae. Spectroscopic data for luminous novae in M31 are also

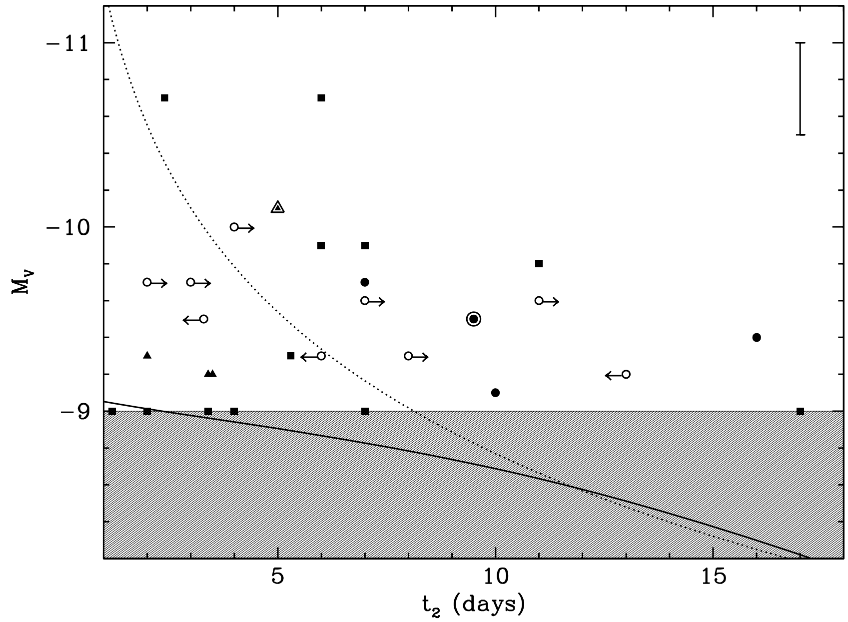

Figure 6. Absolute magnitudes of novae with $M_V \lesssim -9.0$ taken from Tables 4, 5, and 6 are plotted as a function of the time to fade by 2 mag, t_2. Novae lying in the shaded region (below our luminosity cutoff) are not plotted. The filled squares, circles and triangles represent Galactic, M31, and LMC novae, respectively. Open circles represent M31 novae with only upper or lower limits available for t_2. The filled circle surrounded by an open circle represents M31N 2007-11d, and for comparison the similar object, Nova LMC 1991, is shown as a filled triangle surrounded by an open triangle. The error bar in the upper right shows the estimated uncertainty in M_V for a typical nova. The solid and dotted lines represent the MMRD relations of Della Valle & Livio (1995) and Downes & Duerbeck (2000), respectively.

limited, but preliminary data again suggest that He/N novae tend to be slightly more luminous than the Fe II systems (A. W. Shafter et al. 2009, in preparation). In M31 generally, Shafter (2007a) found that ~15% of M31 novae with measured spectra fall into the He/N class, which is comparable to, but slightly smaller than, the percentage seen in the Galaxy. If this difference is found to be statistically significant, it is possible that the slightly higher fraction of He/N novae observed in the Galaxy (and possibly in the LMC) is reflecting either the selection bias in favor of "disk" novae, or the slightly later Hubble types of the Milky Way and the LMC compared with M31, or both.

3.4. The Rise Times of Luminous Novae

In addition to its classification as an unusually luminous Fe II nova, M31N 2007-11d may be atypical in another respect. In comparison with most Galactic novae, the timescale of its rise to maximum light ($\gtrsim$ 4 days) appears, at first glance, to be atypically slow for such a luminous nova. Although observations of the rise to maximum in Galactic novae are fragmentary, the existing observations seem to indicate that essentially all novae reach maximum light within 3 days (Payne-Gaposchkin 1957; Warner 1995, 2008). For the fastest (and most luminous) novae, the rise to maximum is believed to be less than 2 days, and in the case of V1500 Cyg, it may have been less than a day (Liller et al. 1975). The scarcity of pre-maximum data can be attributed to the rapid rise, which results in most novae being discovered either at, or more typically shortly after, maximum light. Strictly speaking, the rise time estimates given in Table 4 are best considered lower limits since pre-maximum observations do not often extend more than a few magnitudes below maximum light. Although the statistics are poor, of the seven novae for which rise times can be constrained, the two Fe II novae appear to have taken the longest time to reach peak brightness. It is tempting to speculate that the similarly slow rise to maximum observed in M31N 2007-11d might be related to its Fe II nature.

The dearth of reliable data on the rise times of Galactic novae is in part a result of how these objects are discovered: usually serendipitously, often in patrols for solar system bodies such as comets and asteroids. However, most M31 and LMC novae have been discovered in targeted surveys, some of which may have sufficiently frequent temporal sampling to better constrain a nova's rise time to peak brightness. Referring to Tables 5 and 6, we see that sufficient data are available for about half of these novae to establish that rise times of up to 4 days are perhaps not as uncommon as the Galactic data would suggest.

One nova in particular, Nova LMC 1991, stands out as being remarkably similar to M31N 2007-11d. Nova LMC 1991 is the brightest nova to be observed in the LMC (and one of the brightest extragalactic novae on record), reaching $M_V \simeq -10.1$. Despite its high luminosity, Nova LMC 1991 usually took a long time to reach maximum light ($t_R \simeq$ 10 days); and, like M31N 2007-11d, it has been classified as a member of the Fe II spectroscopic class (Williams et al. 1994). Schwarz et al. (2001) have modeled the spectral evolution of Nova LMC 1991 during eruption and concluded that the luminosity was super-Eddington before visual maximum, and that the ejected mass was $\sim 3 \times 10^{-4}$ $M_\odot$, which is about an order of magnitude larger than that normally observed in "fast" novae. They argued that the high luminosity and large ejected mass resulted from accretion of low-metallicity material onto a relatively cool, high-mass white dwarf. The low metallicity allows more material to be accumulated before a TNR is triggered than would otherwise be possible for accretion onto a massive white dwarf. The result is an energetic eruption characterized by a high-shell mass and a relatively slow photometric evolution. It is plausible that M31N 2007-11d represents a similar system.

In view of available evidence, we conclude that the rise time of ~4 days observed in M31N 2007-11d may not be as atypical as initially assumed, and is likely the result of a relatively high ejected mass. Unfortunately, with the exceptions of M31N 2007-11d and Nova LMC 1991, few spectroscopic classifications are available for other luminous novae with well-determined rise times. Thus, at present, we cannot draw any conclusions regarding possible correlations between spectroscopic class and the rise time to maximum light.

4. CONCLUSIONS

Our principal conclusions are summarized as follows.

1. M31N 2007-11d was one of the most luminous novae to be discovered in M31 over the past century. After a relatively slow rise to maximum light, the nova reached $R = 14.9$ on 2007 Nov 20 UT.
2. Extensive photometry obtained on the subsequent decline from maximum light showed that the nova could be classified as a relatively "fast" nova, that took $\sim$9.5 and $\sim$13 days to decline 2 and 3 mag from maximum light, respectively.
3. Spectroscopic observations obtained the day following maximum light, and again $\sim$2 and $\sim$3 weeks post-maximum reveal relatively narrow (FWHM $\sim$ 2300 km s^{-1}) Balmer and Fe II emission lines that clearly establish M31N 2007-11d as a member of the Fe II class in William's (1992) system.
4. Among the most luminous Galactic novae with $M_V \leqslant -9$, only one in four is of the Fe II type despite the fact that $\sim$80% of all Galactic novae are members of this class. Thus, M31N 2007-11d appears to be relatively rare in this respect.
5. The photometric and spectroscopic properties of M31N 2007-11d appear to be remarkably similar to that of another extragalactic nova, Nova LMC 1991 (Della Valle 1991; Schwarz et al. 2001). In particular, both were Fe II novae that reached absolute magnitudes brighter than $M_V = -9$, and were characterized by relatively slow rises to maximum light.
6. Although there is considerable scatter at the upper end of the MMRD relation, we find no compelling evidence for a *distinct* class of super-bright novae. The large scatter in luminosity among novae with $M_V \lesssim -9.0$ in Figure 6, coupled with the smooth drop-off in the luminosity distribution in Figure 5, is consistent with the uniform variation expected from a combination of observational uncertainties and intrinsic variability in fundamental nova parameters.
7. The rise time to maximum light for Galactic novae is poorly constrained, but has been generally regarded to be of order 1 to 2 days for the most luminous novae. A comparison with available data for luminous M31 and LMC novae, such as M31N 2007-11d and Nova LMC 1991, shows rise times up to 4 days may not be unusual, and suggests that Galactic nova rise times may have been underestimated.

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